ESD-TR-65-576

HUMAN DIFFERENTIAL SENSITIVITY TO VIBROTACTILE STIMULATION USING A PASSIVE ENVIRONMENTAL SENSOR

John Coules
Donald L. Avery

November 1965

DECISION SCIENCES LABORATORY
DEPUTY FOR ENGINEERING AND TECHNOLOGY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 7682, Task 768201

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FOREWORD

This research was performed at the Decision Sciences Laboratory, Electronic Systems Division, Air Force Systems Command, as part of Project 7682, Man-Computer Information Processing, Task 768201, Data Presentation and Human Data Processing.

This Technical Documentary Report has been reviewed and is approved.

Donald W. Connolly

DONALD W. CONNOLLY
Chief, Display Division
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Director
Decision Sciences Laboratory

ABSTRACT

A passive environmental sensor was evaluated as an input device capable of presenting tactile data to a human. The experiment provided information on the ability of the human to detect differences within the range of the vibratory transducer. Frequency discrimination thresholds showed wide differences between subjects and a significant increase in human sensitivity at one point of the frequency input levels. This increased sensitivity was explained in terms of the resonant frequency of the vibrator and also in terms of the generally known high human sensitivity for amplitude and frequency changes at 200-300 cps. It was concluded that for fine-grain data discrimination individual differences may influence the final design of the sensor. However, these differences may be reduced and the sensitivity of the user improved if its electronic design and its transducers provide redundancy to the human.

HUMAN DIFFERENTIAL SENSITIVITY TO VIBROTACTILE STIMULATION USING A PASSIVE ENVIRONMENTAL SENSOR

John Coules & Donald L. Avery

There is a wide and serious interest in exploring the human tactile system as a method of communication (Geldard, 1962; Bliss, et al., 1965). A variety of transducers, such as, mechanical vibrators and airjets, have been proposed to provide the human with data over a wide range of events from simple environmental data (Bishop, 1963) to complex reading material (Lucas, et al., 1964; Bliss, et al., 1965). Many types of sensors and driving mechanisms could be used to activate the transducers. One kind of sensor, in particular, a photoconductive cell, has been proposed to indicate changes in light intensity as patterns of lights and darks or texture of the normal visual environment. It is known that these patterns are the physical basis for the perception of objects and background (Gibson, 1950). The detected changes in light intensity can be transformed to a vibratory mode of stimulation and thus provide a basis for perception of the environment through the tactile sense.

The passive environmental sensor used in this study does provide tactile data to the human.* Essentially, it is a photoconductive cell and a solid-state square wave oscillator which drives the mechanical vibrator

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* Designated as the BLES (Bishop-Lucas Environmental Sensor) and built by Robert L. Lucas, Santa Rita Technology, Inc., who loaned it to the authors for this investigation.

producing the tactile stimulations. Although from a human engineering viewpoint, the kind of data provided to the person is the major concern, the ability of the person to detect and discriminate the vibration data provided must also be considered. His capabilities may be constrained by the limitations of the transducer. On the other hand the transducer may be capable of providing frequency and amplitude data which exceeds the capabilities of man. Therefore, a close examination of the man-machine interface is necessary. At one level of the man-machine interface, the designer is concerned in selecting a transducer which is congruent with the sensory capabilities of man and which is directly dependent upon the intensity of the light incident to the photoconductive cell of the device. The investigator would attempt to determine the human's ability to discriminate vibrotactile stimulations of changing light intensities. The results would provide information on the ability of the human to detect differences within the range of the vibrator. It would not give us information about objects because a photocell can only deal with light gradients which is a one dimensional event, whereas, the physical definition of objects as a pattern of lights and darks is a two-dimensional event. The one dimensional type of sensor would require many scans and a great deal of learning to identify or recognize an object or detect terrain changes. Thus, it would impose a huge task on the person and make him appear of limited capability. If the designer is interested in providing man with immediate object recognition of events then he probably would utilize a different or, at least, a two-dimensional type of sensor. In this case, the investigator would be

concerned with a higher level of the man-machine interface than the one used in this study.

The purpose of this study was to determine the ability of the human to discriminate differences in vibration applied to the skin using a passive environmental sensor which detects differences in light intensity.

In laboratory studies of vibrotactile frequency discrimination the transducer is the major piece of equipment used, and the control for amplitude changes is critical (Goff, 1959). However, in an integrated environmental sensor, such as, the BLES, amplitude changes and the sound made by the mechanical vibrator are additional cues. Thus, the user receives highly redundant information, because these variables are proportional to frequency. Casual usage of the device may cause the user to feel that it is quite sensitive to light intensity changes. Only when the device is subjected to experimental investigation can a realistic evaluation be made. Regardless, what characteristics the sensor has, it is necessary to show how the results obtained under ideal conditions with a transducer compare with those using the sensor.

Apparatus and Procedure

Seven female undergraduates served as subjects. None had any prior training in experiencing mechanical vibrations.

The BLES environmental sensor consists of a photoconductive cell, Texas Instruments IN 2175, a solid-state square wave oscillator powered

by a 6-volt flashlight battery and a loudspeaker coil which served as the transducer. The tubular device, designed to be held in the hand, was 11 1/2 inches long with an 1 1/2 inch diameter.

For the purposes of this study, the flashlight battery was replaced by a 4 cell NEDA 907 6-volt battery which provided a constant output.

The sensor was rigidly mounted eleven inches from a table top. An opaque rear-projection screen served to diffuse the incident light from a Bell-Howell, 750 watt, Robomatic projector. An illuminated spot 3 x 4 inches in size was projected on the screen which was larger than the 3/8 inches iris diaphragm in front of the sensor's photocell. Stray light could not affect the sensor because its faceplate was flush with the screen. Kodak neutral-density Wratten filters provided five levels of brightness between 1.77 - 360 apparent ft-candles, Table 1 (Appendix A). All brightness measurements were made independently by two experienced observers using a MacBeth Illuminometer. These levels in turn provided five vibration levels between 8.0 - 425 cps, Table 2 (Appendix B). No attempt was made to control for amplitude changes as a function of frequency. For calibration purposes, the vibrator was periodically monitored throughout each session in the following manner. A Turner crystal microphone, model 82, was mounted one centimeter above the vibrator and was connected to a high impedance input pre-amplifier whose output was fed into a Tektronic oscilloscope #533A. Peak to peak measurement of the resultant wave was the recorded frequency. Variations observed in Tables 1 and 2 were produced by slight adjustments made in the equipment. Mean values for the five levels for

brightness and frequency appear in Table 3. The relationship between brightness levels and vibration frequency appears in Appendix C.

Each subject was seated at the table on which the sensor was mounted and given the instructions (Appendix D). All subjects had normal audiograms. This precaution was taken because they were exposed to a moderately high level of noise. To prevent fatigue and adaptation to the vibrations, they were told to use successive fingers, starting with the index finger and excluding the thumb, on each set of four trials. Thus, on the fifth trial they used the index finger again. They were blindfolded to avoid visual cues and a white noise generator, Grason Stadler #456, produced 85 db noise in a range of 50 - 1000 cps to mask the vibrator frequencies. To exclude all vibrations except those emanating from the contactor, the casing of the sensor was covered with 1/2 inch foam rubber and the subject rested her elbow on a 1 inch foam rubber pad. A small 3/8 inch hole in the foam rubber surrounding the sensor's casing provided access to the contactor without excessive damping on the part of the subject's finger. The contactor on the vibrator was 5mm in diameter.

Frequency discrimination thresholds were obtained by the up-down method, a modified method of limits (Guilford, 1954, p. 114-115). Threshold data were collected at each of the five frequency levels. Within each level small changes in frequency or steps were provided in the following manner. One to eight sheets of lantern slide cover glass served as filters to reduce the level of brightness in steps of approximately

6 percent. This produced a comparable change in vibration frequency of approximately 4 percent. The calibration curves for the five frequency levels and number of glass sheets are least square fits and appear in Appendix E. Similar calibration curves were obtained for brightness but are not shown. Thus, the subjects were required to discriminate frequency changes of 4 percent within each level. All the stimulus changes introduced within a level constitute a run. The standard stimulus during a run was the actual value of the brightness level presented to the sensor or the equivalent frequency level felt by the subject. All step changes in brightness and frequency (the variable stimuli) were values less than the standard stimulus.

The procedure in the up-down method consisted in presenting the subject with the standard stimulus set at a particular brightness level. Each subject was run at either the second, third or fourth levels first, randomly determined, and then these were followed by the extreme levels, one and five, the most difficult to judge. At the beginning of each run the variable stimulus was noticeably different than the standard which was presented first because glass filter number 5 or 6 was used. Usually subjects reported a "yes" indicating they detected a difference in frequency. The experimenter then proceeded to decrease the difference between the standard and variable stimuli by using glass filter number 4 or 5. This procedure was continued until the subject reversed his response from "yes" to "no." After the first reversal, the variable stimulus was set one increment in the opposite direction to the subject's last response. Twenty responses were obtained for each of the five brightness or frequency levels.

During each trial the noise generator was turned on during the sequential presentation of the two frequencies. The standard stimulus was always presented for 10 seconds after which time the noise was momentarily interrupted alerting the subject that the second or variable stimulus would be presented. The variable stimulus would appear from 1 to 5 seconds later in a random fashion and would remain on from 9 to 5 seconds respectively. The noise was interrupted for a longer period of time and at the same time a diaphragm shutter occluded the light from the projector which made the sensor inoperative. This served to inform the subject to make a response. Periodically, blanks or no physical differences between the two stimulus presentations were presented as a check on the subjects judgments.

Results and Discussion

The average discriminable changes in frequency detected by the subjects at each level appears as delta f in the second column in Table 2 (Appendix B). Figure 1A shows the relationship between the mean delta values against levels. This curve is consistently lower but in general agreement with previous findings (Goff, 1959). One reason why lower delta f values were obtained was that amplitude, which changes as a function of frequency, operated freely. These changes could serve as cues and may account for the differences observed. A second factor that could influence the results was that the subjects used different fingers on successive trials. Thus, fatigue and adaptation, which tend

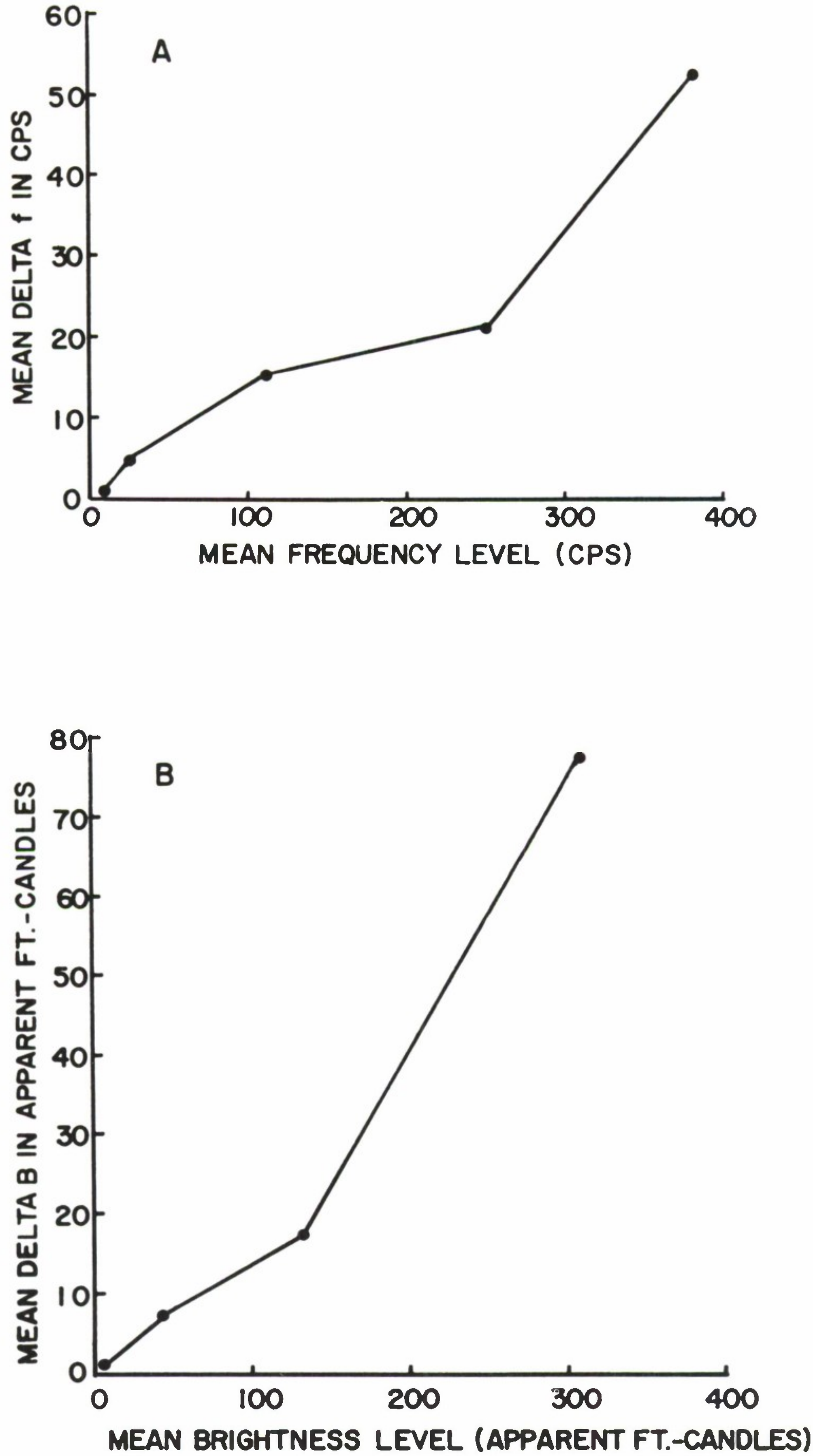

Figure 1. Mean delta values for the five frequency levels (A) and for the five brightness levels (B).

to raise thresholds, would not be operating to affect the thresholds, whereas, in Goff's study the index finger was used throughout.

The ratio of each delta value to a given level is the Weber fraction and indicates the sensitivity of the subjects. It appears in column three of Table 2 (Appendix B). It is apparent that there are wide differences between subjects in the frequency discrimination thresholds. For example, subject NS could detect differences of 4:100 showing a high degree of sensitivity, whereas, subject JC's ratio is 4:1 at the same vibration level of 392 cps. This means that, for fine-grain data discrimination, individual differences is a problem which may influence the design of the final configuration of the sensor.

As our interest was to study the general characteristics of the sensor as a tactile transducer, the subjects' data were pooled and the mean values appear in Table 3. The mean Weber fractions are plotted in Figure 2. As frequency level increases from a mean value of 9 to 383.5 cps a noticeable dip occurs at 252 cps, log 2.40, on the graph. This is contrary to the findings of Goff's study in which Weber fractions increased from 25 to 200 cps. The range in her study was from .21 to .55 and from .18 to .38 at two amplitude levels, whereas in this study, in which amplitude varied at some unknown level, the Weber fractions for frequency were from .08 to .16. These lower values may be explained on the basis that amplitude changes gave the subjects additional data. This, however, may not be the entire explanation of the results observed. The dip in the curve is of the order of 2:1 and, in part, may be a result of

Table 3

Mean Values of Delta and Weber Fractions-S's Pooled

Vibration

Mean Frequency Level in cps	Delta f in cps	Weber Fraction
9.0	1.47	.16
28.8	4.56	.16
111.1	15.0	.14
251.8	21.0	.08
383.5	52.4	.13

Brightness

Mean Brightness Level in Apparent ft.-Candles	Delta b	Weber Fraction
2.08	.42	.20
8.52	1.60	.19
41.97	6.84	.16
133.5	17.5	.13
308.9	77.0	.25

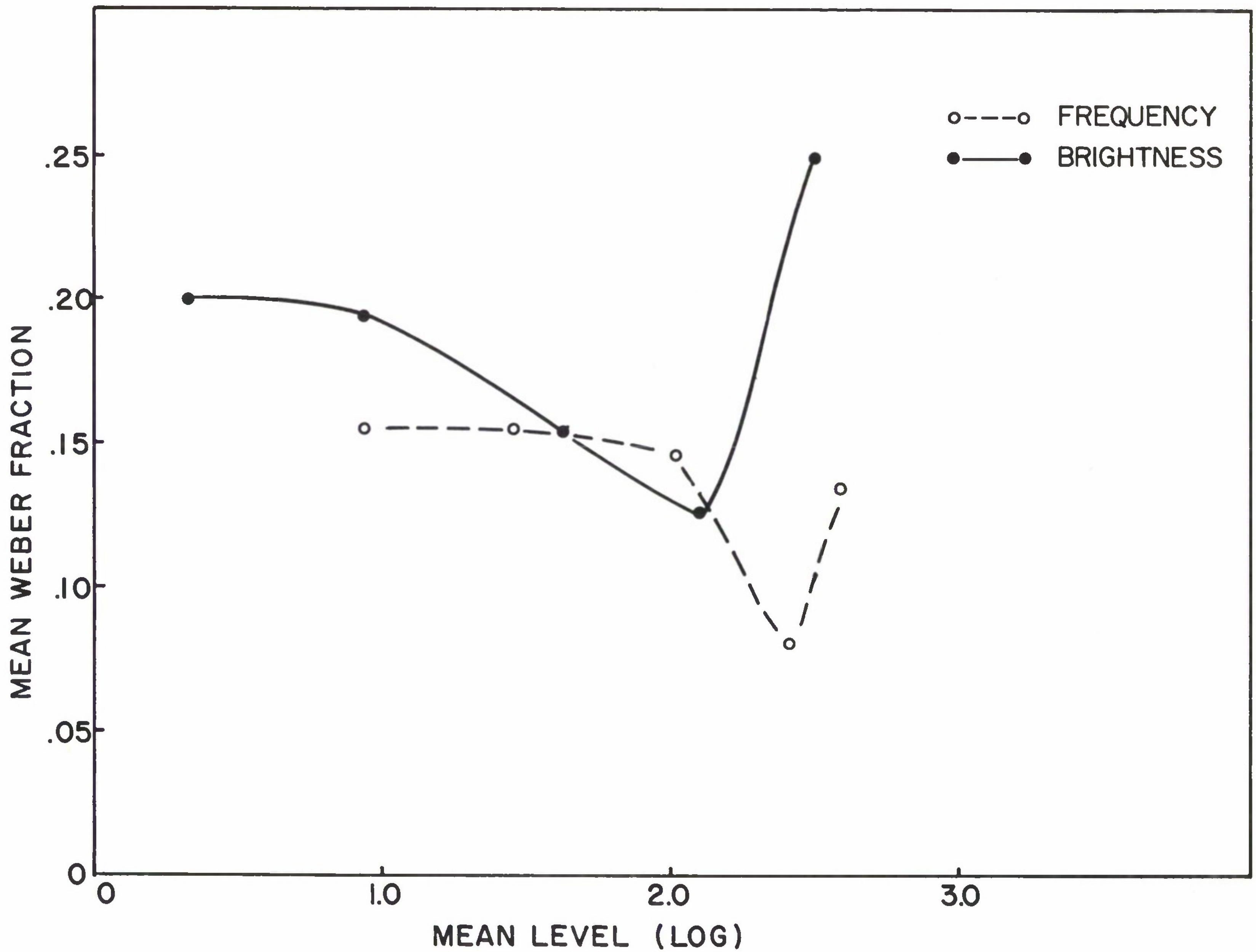

Figure 2. Mean Weber fractions for the five levels of brightness and frequency in log units, base 10.

the resonant frequency of the vibrator used. The measured value lies between 205 and 250 cps depending upon the output impedance of the oscillator driving the vibrator. This resonance effect could account for only 10 percent of the improved sensitivity of our subjects and in the event the vibrator contactor is damped by the subject's finger this value is essentially reduced to zero. A second, and more plausible, reason is that the range of maximum sensitivity of frequency and amplitude is between 200 - 300 cps (Geldard, 1962; Verrillo, 1962). The subjects indeed show increased sensitivity, i.e., a lower Weber fraction, within this range at 252 cps in Figure 2.

The ability to sense the environment with the BLES unit is a joint function of the human and the vibrator. The characteristic sensitivity curve obtained for frequency should be reflected in the analysis of the brightnesses detected by the photocell which also serves as a transducer between the environment and the sensor. Figure 1B shows the mean delta values as a function of brightness levels. This curve is very similar to the frequency curve in Figure 1A. The delta values for the brightness thresholds and the Weber fractions for each subject and each level appear in Table 1 (Appendix A). Comparing the Weber fraction of frequency (Table 2) with that of brightness (Table 1), the brightness values are consistently higher. In fact, the mean difference is slightly over 5%. This may be due to a decrease in efficiency resulting from the transformation of radiant energy from the photocell through the solid-state square wave oscillator of the sensor, and finally through the vibrator to the human. Since the human is the last link in the system, his performance is the

criterion of the sensor's performance. Thus, the performance of the BLES unit as a passive environmental sensor is a joint function of the performance of the vibrator-human link and the performance of the electronic devices. The Weber fractions for brightness are the appropriate values to determine the sensitivity of the sensor as a system. Table 3 and Figure 2 illustrate the Weber fractions obtained. This figure may serve as an indication of overall system efficiency.

To improve the sensitivity of this sensor system, improvement of the electronic components and transducers and/or providing redundancy to the human via additional cues, such as, amplitude changes and auditory cues, could make this passive environmental sensor a useful device.

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APPENDIX A

Table 1

Brightness levels, Delta B, and Weber fractions by subjects.

	Brightness level apparent ft - candles	Delta B	Weber fraction
Subject: SL	2.45	.56	.23
	8.41	2.42	.29
	41.95	6.03	.14
	131.1	18.0	.14
	279.0	91.8	.33
Subject: LP	1.96	.51	.26
	8.41	.67	.08
	41.95	11.76	.28
	131.1	14.0	.11
	279.0	53.8	.19
Subject: JB	1.78	.24	.14
	8.74	1.39	.16
	41.95	5.14	.12
	131.1	8.6	.07
	359.7	46.7	.13
Subject: SD	1.77	.19	.11
	8.15	1.60	.20
	41.95	5.08	.12
	136.6	12.6	.09
	303.1	72.0	.24
Subject: NS	2.17	.42	.19
	9.07	1.42	.16
	40.81	6.40	.16
	136.6	18.0	.13
	279.0	25.0	.09
Subject: JC	1.77	.38	.21
	8.15	1.23	.15
	41.95	7.19	.17
	136.6	32.5	.24
	303.1	138.6	.46
Subject: DL	2.66	.66	.25
	8.73	2.46	.28
	43.25	6.28	.14
	131.1	18.5	.14
	359.7	110.8	.31

APPENDIX B

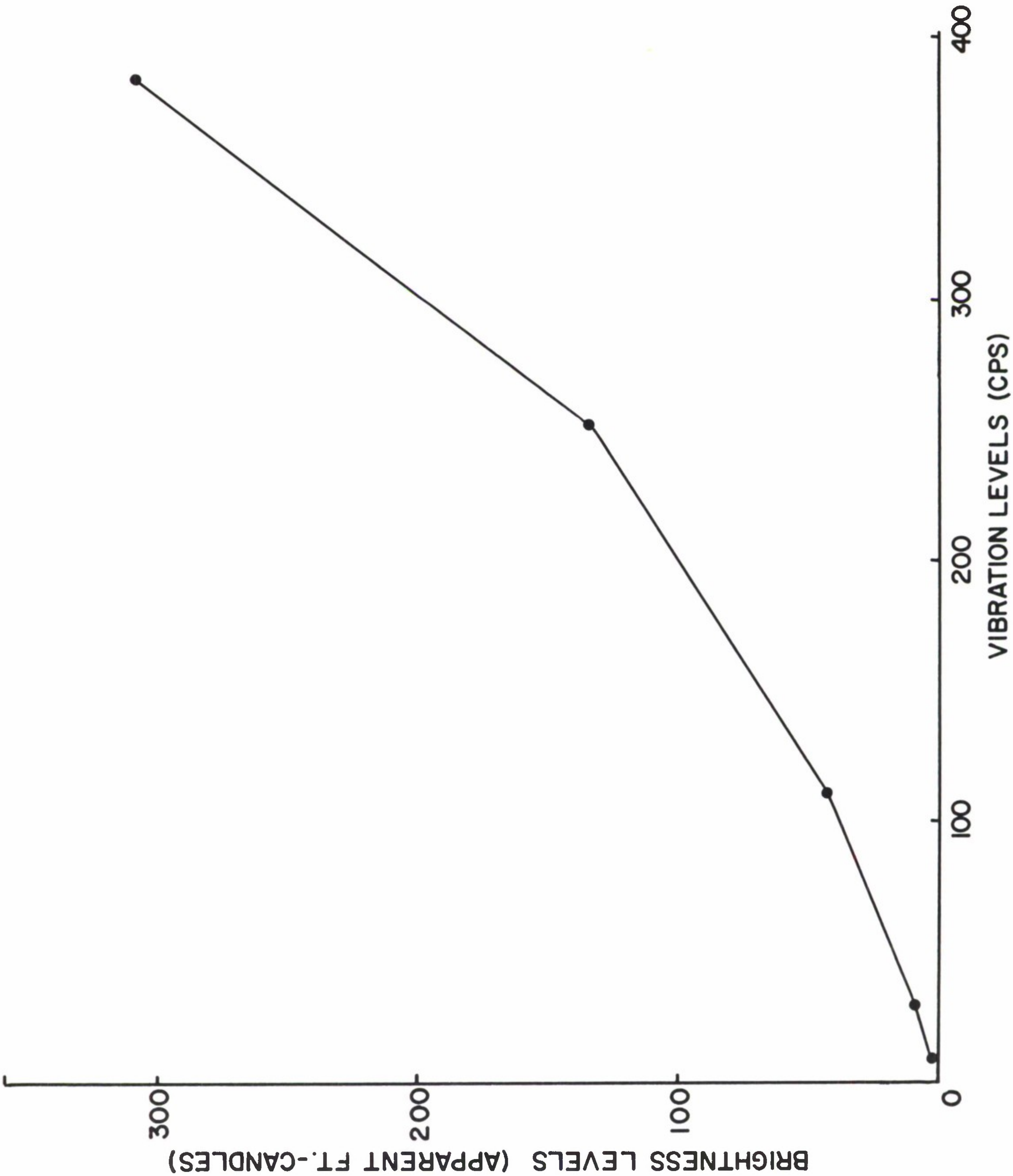
Table 2

Vibration levels, Delta f, and Weber fractions by subjects.

	Vibration levels cps	Delta f	Weber fractions
Subject: SL	10.2	1.95	.19
	28.5	7.0	.24
	111.0	12.8	.12
	250	21.8	.09
	377	64.7	.17
Subject: LP	8.6	1.78	.21
	28.5	1.9	.07
	111.0	26.9	.24
	250	16.9	.07
	377	37.1	.10
Subject: JB	8.0	.85	.11
	29.4	3.9	.13
	111.1	11.1	.10
	250	10.3	.04
	425	29.2	.07
Subject SD	8.0	.68	.08
	27.8	4.6	.16
	111.1	10.6	.10
	256	15.0	.06
	392	48.2	.12
Subject: NS	9.3	1.44	.16
	30.3	4.0	.13
	108.7	14.2	.13
	256	21.4	.08
	392	16.2	.04
Subject: JC	8.0	1.30	.16
	27.8	3.5	.13
	111.1	15.6	.14
	250	39.1	.15
	392	96.9	.25
Subject: DL	10.9	2.26	.21
	29.4	7.0	.24
	113.6	13.7	.12
	250	22.4	.09
	425	74.3	.18

APPENDIX C

Mean Brightness Levels as a Function of Mean Vibration Levels



APPENDIX D

Instructions

VIBRATION DISCRIMINATION EXPERIMENT

"The laboratory is currently interested in the feasibility of presenting information to man through senses other than those of hearing and vision. The instrument that you see before you transforms light energy into physical vibration.

The purpose of this experiment is to measure your ability to detect frequency changes in vibratory stimulation on your finger. These changes will vary in size from large to small and therefore will also range in difficulty from being easy to detect to being very hard to detect so you must pay close attention. On some trials there will not be any change. There are no right or wrong answers to this test. To insure that nothing distracts you, we have provided this light shield for your eyes and a masking noise through the headset to block out any extraneous sounds.

Here is your task on each trial. Place your right index finger here on the vibrator. (E indicates). Just rest your finger lightly on the sponge. Do you feel the vibration? Fine! On each trial you will be presented a vibration at one frequency level which will be on continuously. I will say ready to indicate the beginning of each trial. Just before the drop in frequency occurs, I will signal you by interrupting the noise once. Remember, there may not be any change on a given trial. In order that your finger does not fatigue, use successive fingers on each trial, starting

with the index finger on the first trial. Do not use your thumb. Thus, on the fifth trial you will use your index finger again. After the second vibration frequency has occurred, I will signal you of that fact by interrupting the noise twice in rapid succession. You are then to tell me if you detected any change in vibration by "yes" or "no." Sometimes the task will be difficult, other times easy, pay careful attention to the vibrator on each trial.

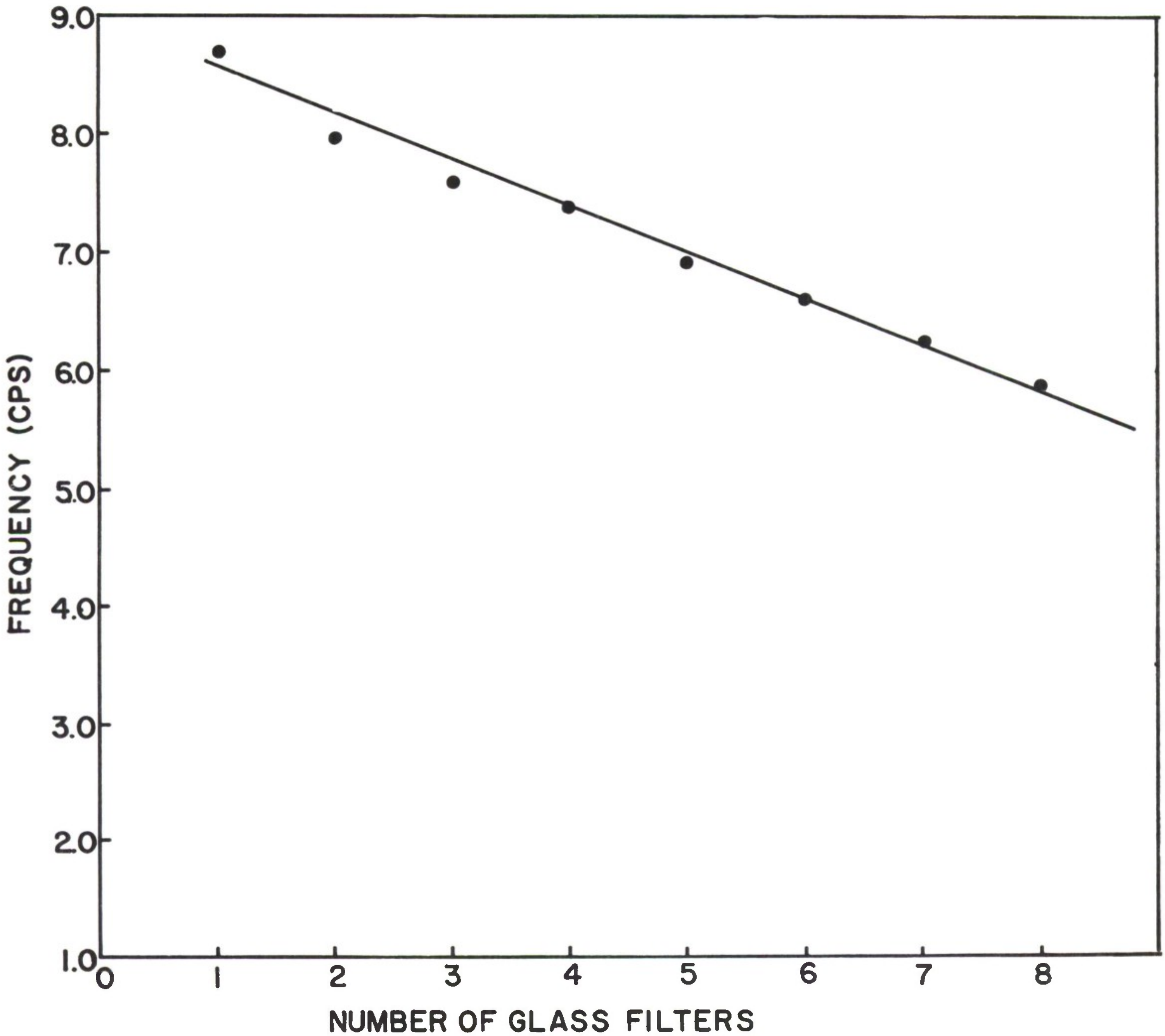
Now put on the earphones and I will demonstrate what I've just outlined. The frequency change that you will notice will be much greater than those that will be presented during the actual test.

Are there any questions?"

APPENDIX E

Vibration Frequency as a Function of Number of Glass Filters

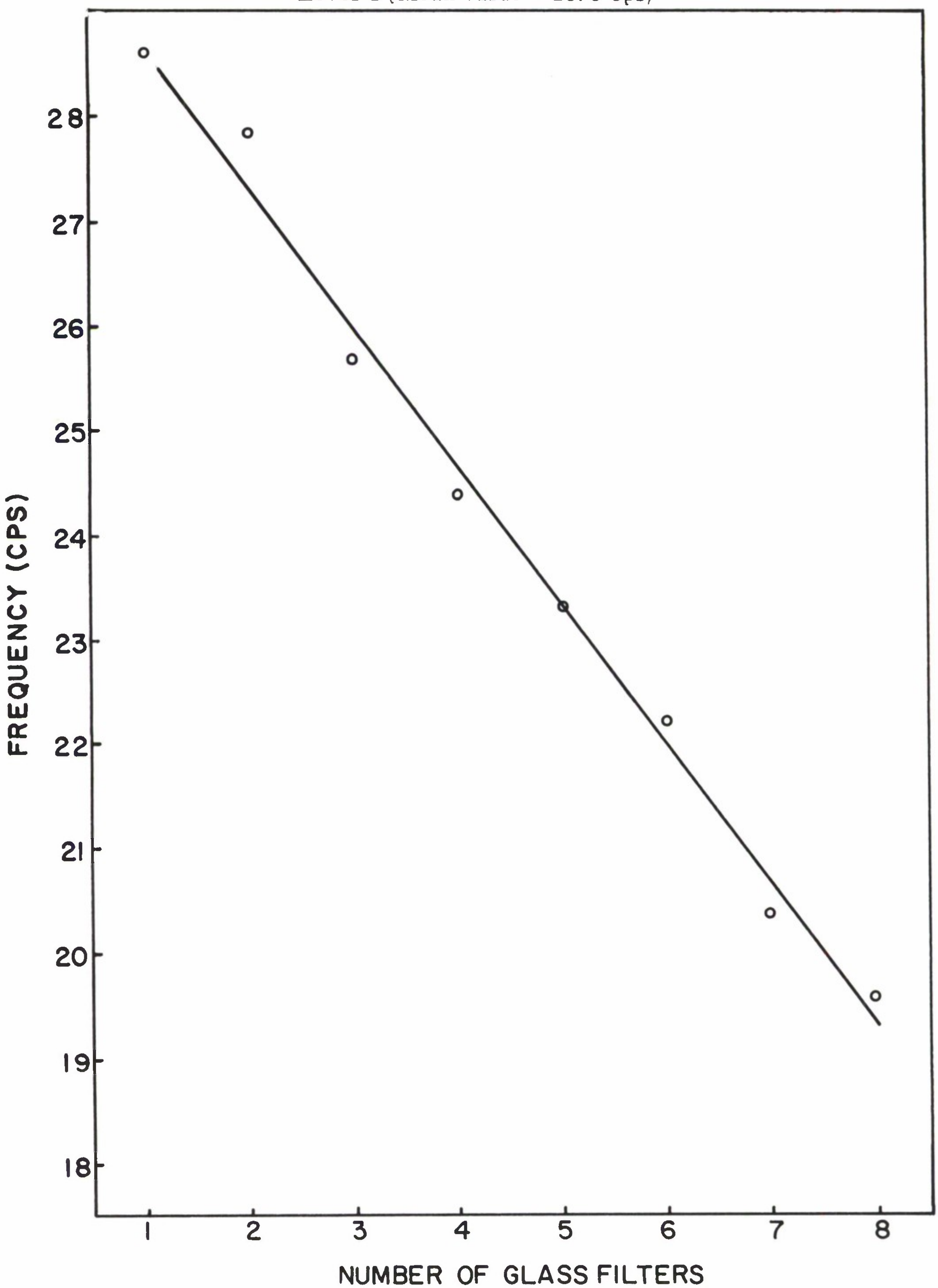
Level 1 (Mean value = 9.0 cps)



APPENDIX E

Vibration Frequency as a Function of Number of Glass Filters

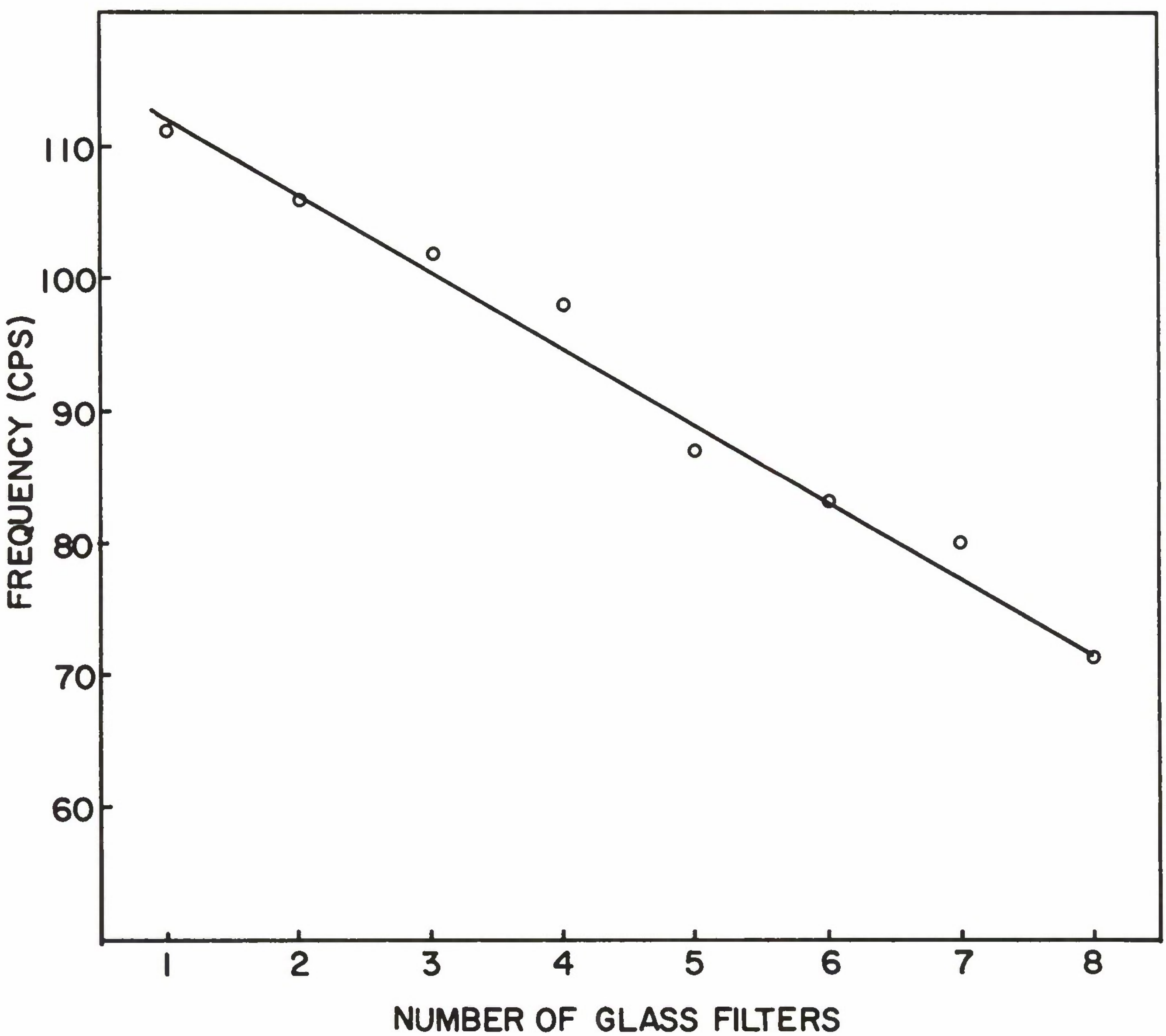
Level 2 (Mean value = 28. 8 cps)



APPENDIX E

Vibration Frequency as a Function of Number of Glass Filters

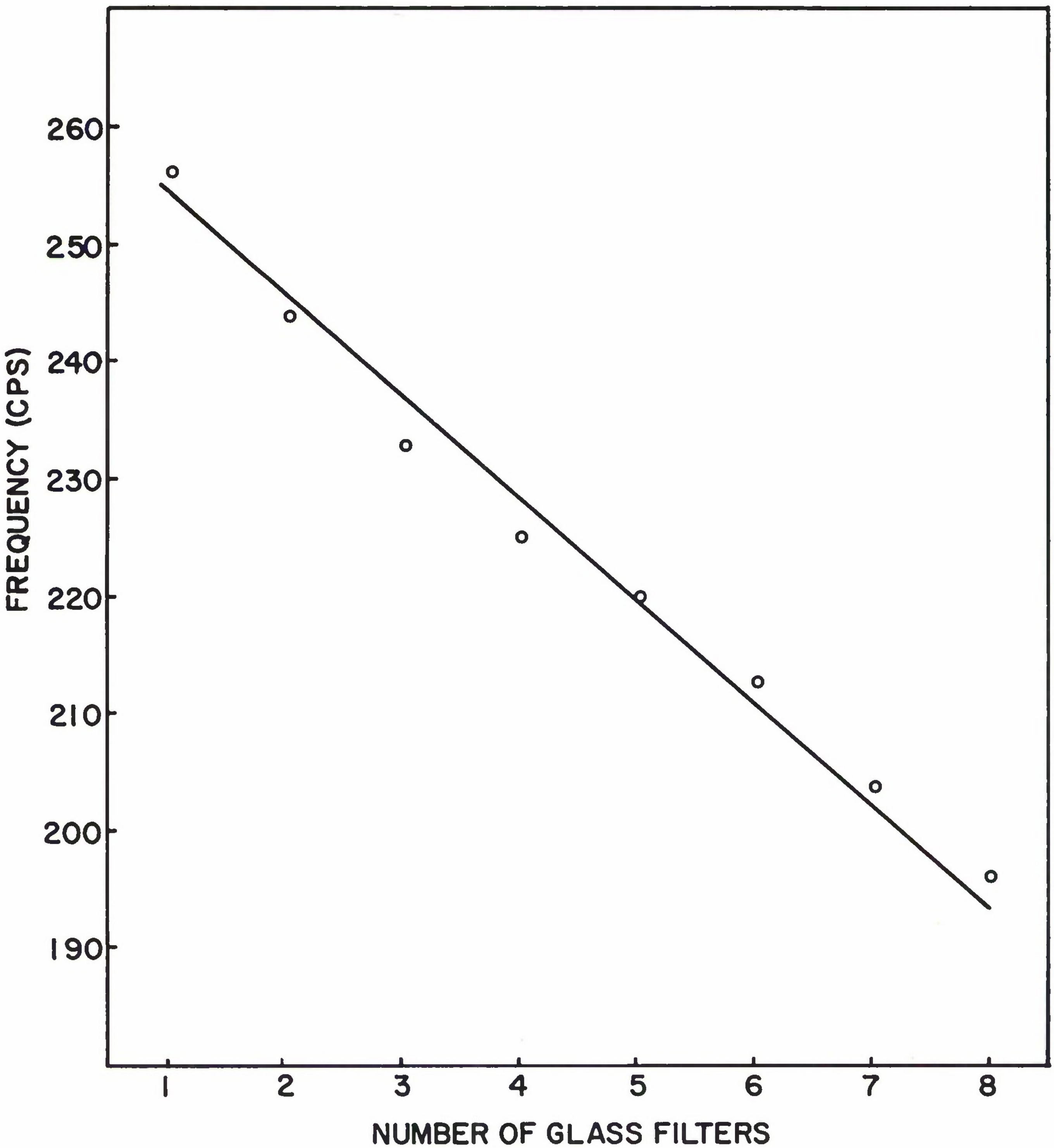
Level 3 (Mean value = 111.1 cps)



APPENDIX E

Vibration Frequency as a Function of Number of Glass Filters

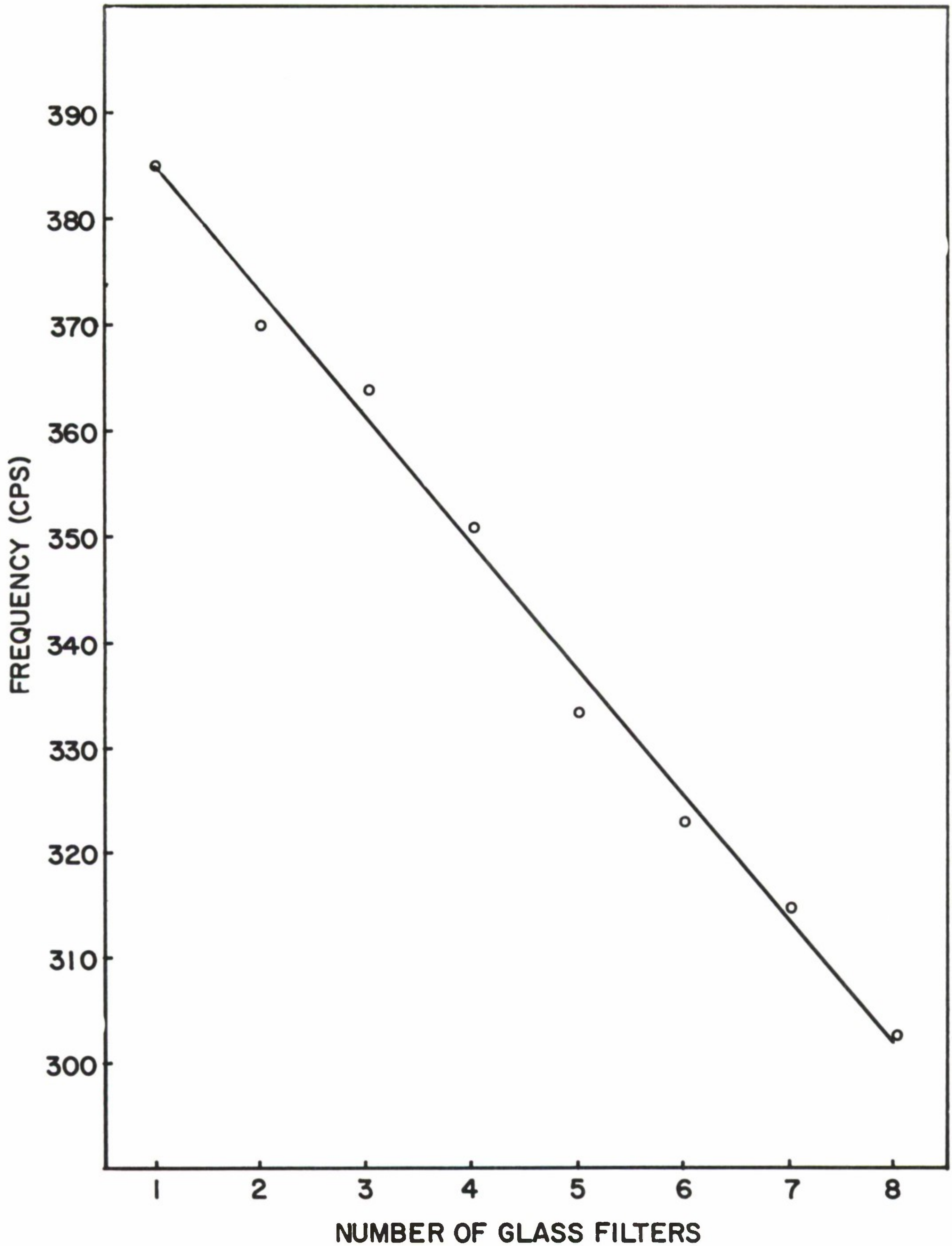
Level 4 (Mean value = 251.8 cps)



APPENDIX E

Vibration Frequency as a Function of Number of Glass Filters

Level 5 (Mean value = 383.5 cps)



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13. ABSTRACT

A passive environmental sensor was evaluated as an input device capable of presenting tactile data to a human. The experiment provided information on the ability of the human to detect differences within the range of the vibratory transducer. Frequency discrimination thresholds showed wide differences between subjects and a significant increase in human sensitivity at one point of the frequency input levels. This increased sensitivity was explained in terms of the resonant frequency of the vibratory and also in terms of the generally known high human sensitivity for amplitude and frequency changes at 200-300 cps. It was concluded that for fine-grain data discrimination individual differences may influence the final design of the sensor. However, these differences may be reduced and the sensitivity of the user improved if its electronic design and its transducers provide redundancy to the human.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Perception						
Vibration						
Discrimination						
Tactile						
Sensor						

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